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Chairman Babin, Ranking Member Edwards, Chairwoman Comstock, Ranking Member Lipinski, and Members of the Subcommittees, it is my privilege to share with you the recent findings of the Astronomy and Astrophysics Advisory Committee (AAAC).

I am Angela V. Olinto, Professor of Astronomy & Astrophysics at the University of Chicago, and current Chair of the AAAC. The AAAC is a Federal Advisory Committee Act (FACA) committee established under the National Science Foundation (NSF) Authorization Act of 2002 and amended by the Department of Energy (DOE) High-End Computing Revitalization Act of 2004.[1] This thirteen member committee of leading US astronomers and astrophysicists is charged to assess and make recommendations regarding the coordination of astronomy and astrophysics programs of the NSF, the National Aeronautics and Space Administration (NASA), and the DOE; and the status of the activities relative to the priorities of the 2010 National Research Council (NRC)[2] decadal survey *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*)[3] and its predecessors. I have served as a member of the AAAC from 2003 to 2006 and again starting in 2013.

Astronomical Progress in Astronomy and Astrophysics

Over the last few decades, astronomers and astrophysicists have revolutionized our understanding of the universe, our place in it, and the fundamental laws that govern its evolution and the systems it contains. These discoveries have captivated the public and inspired new generations of scientists and engineers to continue to expand our knowledge and secure our future leadership in science, technology,

[1] http://www.nsf.gov/mps/ast/aaac/charter.pdf
[2] The National Academies was the National Research Council in 2010.
[3] http://www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

and space. These impressive achievements are the direct result of the long-standing national investment in basic scientific research in the US.

This year the world witnessed the historic breakthrough of the first observations of gravitational waves by the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO). Announced on February 11th, this discovery crowned the century-old effort to understand Gravity, the most challenging force to master. The observed signal confirmed the predictions of Einstein's general relativity and opened a new window onto the universe. The recently reported second LIGO event hails the new era of observations that will transform our view of the universe. This momentous discovery demonstrates the power of long-term investment in basic research by the US through the NSF and the ability of scientists worldwide to work together in the challenging and fascinating quest to understand nature.

The new gravitational wave window enables more direct observations of the most extreme events in our universe, including the earliest moments of the Big Bang. This new window adds a completely new dimension to traditional observational astronomy, which is based on the broad electromagnetic wave spectrum. Electromagnetic waves currently provide the bulk of our knowledge, from the earliest moments of the universe to planetary systems in our neighborhood of the Galaxy.

Combined space and ground-based astronomical observatories have recently shown that the universe is not only expanding but its expansion is accelerating due to a yet to be explained dark energy component, and that most of the matter in the universe is not normal matter, but dark matter. In addition, led by the NASA Kepler mission, space- and ground-based observatories have revealed a plethora of planetary systems harbored by the hundreds of billions of stars in our Milky Way galaxy, motivating the ongoing search for Earth-like habitable planets.

Adding to electromagnetic and gravitational wave observations, measurements of cosmic rays and neutrinos have also blossomed in the last few years with the recently opened window of high-energy astrophysical neutrinos by the NSF-funded IceCube observatory at the South Pole. Together, these three types of observations — light waves, gravitational waves, and cosmic rays and neutrinos — today cover 35 orders of magnitude in frequency, forming the broad palette of Multi-Messenger Astronomy and Astrophysics.

Coordination of Astronomy and Astrophysics Programs

As summarized in the annual AAAC reports, US investment in astronomy and astrophysics continues to support an outstanding portfolio of preeminent research facilities and the coordination between the NSF, NASA, and DOE has been exemplary.

As outlined in the 2013 AAAC report[4], "programmatic partnerships among agencies or involving other entities are appropriate when they deliver increased science capability, cost effectiveness, access to specialized expertise and avoidance of duplication." The same report lists dozens of notable cases of joint agency efforts that have successfully followed these guidelines. The 2014 AAAC report[5] laid down the AAAC Principles for Access,[6] based on the best science, open access, and reciprocity, for current and

[4] http://www.nsf.gov/mps/ast/aaac/reports/annual/aaac_2013_130308finalreport.pdf
[5] http://www.nsf.gov/mps/ast/aaac/reports/annual/aaac_2014_report.pdf
[6] http://www.nsf.gov/mps/ast/aaac/aaac_2014_principles_for_access-v2.pdf

future partnerships among the three agencies assessed by the AAAC and with other partners including private and international entities.

Most of the major science programs recommended by decadal surveys require coordinated and complementary efforts in multi-facility astronomical observations, simulations, theory, and analysis. For example, remarkable results from the Hubble Space Telescope routinely include complementary observations from other space telescopes and ground-based larger aperture optical to radio telescopes, as well as coordinated work on theory and simulations needed to interpret the observations.

Recent outstanding results from well-coordinated projects include the discovery of 17 new Milky Way dwarf satellites by the Dark Energy Survey (DES), a project jointly supported by NSF and DOE. These Milky Way satellites are ideal targets for indirect dark matter searches, which are led by the Large Area Telescope instrument aboard the NASA Fermi Gamma-ray Space Telescope, a partnership between NASA and DOE.

A similar NSF and DOE partnership is now in place to achieve the first large-scale priority of the *NWNH* decadal survey on the ground, the Large Synoptic Survey Telescope (LSST). LSST is a multipurpose, wide-field, optical survey telescope targeting aspects of all three *NWNH* science themes; the cosmic dawn; new worlds; and the physics of the universe. LSST is now under construction and should start its main operations in 2022.

During the past year, the number of exoplanet candidates detected by the NASA Kepler and K2 missions surpassed four thousand, vastly expanding our understanding of planets and nurturing the public's spirit of adventure and discovery. (Exoplanet stands for an extra-solar planet or a planet that orbits a star other than the Sun.) Among those candidates, about a dozen are small enough to be rocky and orbit within the Habitable zone of their host stars, where they receive similar stellar radiation to that received by the Earth from the Sun. Among these exoplanets are ones that orbit and transit nearby stars, which scientists can study in more detail with ground and other space-based telescopes. Adding to the exoplanet population studies are observations of the early stages of planet formation by the NSF-funded Atacama Large Millimeter/submillimeter Array (ALMA), which was a top priority from previous decadal surveys and began full operations in 2013.

Addressing the *NWNH* priority of high-precision radial velocity surveys of nearby stars in order to validate and characterize exoplanet candidates and amplify the science impact of the Transiting Exoplanet Survey Satellite (TESS) mission, NASA and NSF recently partnered on the Extreme Precision Doppler Spectrometer (EPDS) instrument funded by NASA to be placed on the WIYN telescope at Kitt Peak National Observatory (KPNO), part of the National Optical Astronomy Observatory (NOAO) funded by NSF.

Another important example of inter-agency cooperation is the study of the earliest moments of the universe with cosmic microwave background (CMB) observations. The search for primordial gravitational waves through the observation of special patterns in the CMB polarization maps (named B-modes) has now reached a third generation of experiments with sensitivity to make this ground-breaking discovery. CMB scientists funded by NSF, DOE, and NASA are planning for a future (Stage-4) ground-based CMB effort, known as CMB-S4, to improve the sensitivity to CMB B-modes by orders of magnitude. The ground-based CMB-S4 effort will complement NASA experiments from balloons and space. On sub-orbital efforts, NASA just demonstrated the new, cutting-edge, super-pressure balloon capability flying the first science payload, the Compton Spectrometer and Imager (COSI), out of Wanaka, New Zealand, for a record 46-day mid-latitude flight.

Status of Decadal Survey Priorities

The AAAC charter directs the committee to assess and advise on the progress of the three funding agencies (NSF, NASA and DOE) on the recommendations made by the astronomy and astrophysics Decadal Surveys from the National Academies. The most recent survey report, *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*) from 2010, was the first to include the DOE. *NWNH* will soon be supplemented by a report from the *Midterm Astronomy and Astrophysics Assessment* committee convened by the National Academies at the request of the agencies. Implementation of *NWNH* is also closely related to other planning exercises, including the Cosmic Frontier recommendations in the Particle Physics Project Prioritization Panel (P5) report (which addresses DOE High Energy Physics and the NSF Directorate for Mathematical and Physical Sciences), the NSF Division of Astronomical Sciences (AST) Portfolio Review, and NASA Astrophysics Division (APD) Senior Reviews.

The 2016 AAAC report[7] highlights the excellent progress by the agencies toward the construction of the highest priorities in the most recent decadal surveys. The highest priority of the 2001 *Astronomy and Astrophysics in the New Millennium*[8]decadal survey, the James Webb Space Telescope (JWST), is on track for its planned October 2018 launch date, thanks to the continued support by Congress.

JWST will be the most powerful telescope ever launched into space. Its four science instruments will operate in the near- and mid-infrared, where light is better able to penetrate regions of gas and dust and is well-suited to the study of highly redshifted stars and galaxies in the early Universe. JWST will provide incisive spectroscopy of transiting exoplanets with properties approaching those of the Earth. On the 4th of February 2016, NASA announced that the full 18-segment primary mirror was completed marking a major milestone for the project. The primary optical system will be integrated with the other telescope components for testing of the observatory at Johnson Space Center in 2016 and 2017.

The highest 2010 *NWNH* large-scale priority in space, the Wide-Field Infrared Survey Telescope (WFIRST), is also progressing well, having moved into formulation phase (Phase A) in February 2016 under strong NASA stewardship of science and project teams. WFIRST is the next-generation, large space observatory designed to perform wide-field imaging and spectroscopic surveys of the near infrared sky. WFIRST will contribute to all three *NWNH* science themes, by answering essential questions about dark energy, exoplanets, and galaxy evolution.

The AAAC commends NASA for adapting to the availability of the Astrophysics Focused Telescope Assets (AFTA) 2.4-meter mirrors, proceeding with mission concept development, and assembling the formulation science teams to enable the start of formulation for this highest-ranked, large space project in *NWNH* by mid-decade. The addition of a coronagraph to WFIRST will augment the exoplanet capabilities of the mission. WFIRST will be able to inaugurate space-based direct imaging in reflected light to pave the way towards the imaging of Earth-like planets in a future flagship mission.

[7] http://www.nsf.gov/mps/ast/aaac/reports/annual/AAAC_2015-16_Report.pdf
[8] http://www.nap.edu/catalog/9839/astronomy-and-astrophysics-in-the-new-millennium

The next *NWNH* priorities for large projects in space are, in order of priority, the augmentation of the Explorer Program, the Laser Interferometer Space Antenna (LISA), and the International X-ray Observatory (IXO). The Explorer Program provides frequent flight opportunities for innovative, streamlined space investigations within the astrophysics and heliophysics science areas. The next Astrophysics Explorers are the mission of opportunity (MOO) Neutron star Interior Composition ExploreR (NICER) currently planned for deployment at the International Space Station in 2017, and the Medium-class Explorer (MIDEX), the Transiting Exoplanet Survey Satellite (TESS), with a launch currently planned for August 2017. TESS will search for candidate Earth-like transiting planets orbiting bright stars close to the sun to provide targets for JWST to follow. A recent Small Explorer (SMEX) announcement of opportunity call led to concept studies of five candidate SMEXs and MOOs. A MIDEX announcement of Opportunity call is planned for later in 2016.

Given budgetary constraints on the ability of NASA to respond to the full *NWNH* program, NASA has partnered with the European Space Agency (ESA) on ESA's second and third large missions (L2 and L3) to respond to the 3rd (LISA) and 4th (IXO) *NWNH* priorities in space. LISA is a low-frequency gravitational wave observatory proposed to complement higher-frequency Earth-based observatories like LIGO and to provide access to new means of studying black holes and making precision tests of general relativity. A technology mission, LISA Pathfinder, led by ESA with NASA partnership, was successfully launched on December 3, 2015. It achieved the lowest acceleration motion ever and tested new sensing technology needed for LISA. The AAAC encourages NASA to continue on its plans to partner with ESA on its L3 gravitational wave observatory mission, which has a tentative launch date of 2034.

IXO is a next-generation X-ray observatory for studies of the high-energy Universe. In 2014, ESA selected a re-scoped X-ray mission, called Advanced Telescope for High Energy Astrophysics (ATHENA), with launch planned for 2028. NASA is working towards US participation in the ESA ATHENA project, providing future access to X-ray resources for the US astronomy and astrophysics community.

As mentioned above, the highest *NWNH* priority for large projects on the ground is LSST, which is progressing well, with a strong NSF and DOE partnership for construction and operations. The second highest priority is the NSF Midscale Innovations Program (MSIP), a competed grants program for mid-scale projects, designed to allow significant advances in scientific discovery beyond the scope of the Astronomy and Astrophysics Grants (AAG) program. Following MSIP in priorities is the Giant Segmented Mirror Telescope (GSMT), a very large, ground-based optical and near-infrared telescope that can provide a spectroscopic complement to the JWST, ALMA, and LSST. Two international consortia led by US institutions are planning GSMT construction: the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT). Finally, the fourth *NWNH* priority for ground-based astronomy is the Atmospheric Čerenkov Telescope Array (ACTA), an international instrument for high-energy gamma-ray astrophysics. Budgetary constraints have not allowed progress on recommendations for a Federal partnership in GSMT nor in ACTA.

The AAAC finds that given the constrained budget realities, the NSF MSIP program is funded at a level well below that envisioned in *NWNH*. In addition, MSIP is becoming the only mechanism available for funding other priority activities advocated in *NWNH*. NSF/AST is funding MSIP at the highest level commensurate with its program balance. However, the program is supporting a larger number of projects with a lower budget than recommended in *NWNH* and is not able to support the higher-cost projects as envisioned by *NWNH*.

In its efforts to follow the recommendations of *NWNH,* NSF/AST initiated a portfolio review process that outlined a plan for divestment of some existing facilities to enable NSF to meet the scientific priorities of *NWNH*. The AAAC commends NSF/AST for finding creative solutions to respond to the recommendations made by the Portfolio Review Committee (PRC). These actions will reduce the amount that NSF/AST will spend on the operating budgets of lower-priority facilities and thus enable the NSF to move closer to the desired balance in the portfolio recommended by *NWNH*. The AAAC recommends that strong efforts by NSF for facility divestment continue as fast as is practical.

Competed Grant Success Rates in US Astronomy and Astrophysics

The last decade has witnessed the construction and operations of world-leading observatories with the potential to secure the long-term leadership of US astronomy and astrophysics. Over the same period funds available for community-wide openly competed grants have remained largely flat in both NSF/AST and NASA/APD. Balance between funding construction and operations of observatories and maintaining a healthy core program of competed grants is crucial for the future of the field. As emphasized in *NWNH* page 4, "Maintaining a balanced program is an overriding priority for attaining the overall science objectives that are at the core of the program recommended by the survey committee."

An unfortunate consequence of the budgetary pressure on the portfolio is the decline of success rates in competed grants as discussed in the AAAC report *Competed Grant Success Rates in US Astronomy and Astrophysics.*[9] From 2004 to 2014, the success rates in the NSF/AST AAG program declined from 30% to 17% and NASA Astrophysics Research and Analysis (R&A) proposal success declined from 30% to about 20%. During the same period no significant changes occurred in the distribution of proposal merit. Declining success rates have affected highly rated proposals, which may cause a loss in momentum for the field as a new generation gets discouraged and new discoveries are missed.

The AAAC reports tell a story of impressive accomplishments by agencies and scientists in the context of the challenging budget environment of the past few years. The AAAC recommends that NSF and NASA continue their challenging work toward balance of the portfolio and believe that a modest increase in investment in the base program is warranted to help alleviate the proposal pressure crisis, and better realize the scientific potential of the leading facilities and missions.

Concluding Remarks

The AAAC is very grateful to the continued support of Congress for basic research in general and astronomy and astrophysics in particular. With the sustaining support from Congress, the well coordinated efforts of the agencies, and the enduring tradition of the community to prioritize its aspirations through the decadal survey process, US astronomy and astrophysics will continue to lead the world in our quest to understand the universe, its laws, origins, and future, and our own origins and future. The astonishing discoveries that we can now only imagine will continue to captivate the public and inspire future generations to study scientific and technical fields that will further enrich the prosperity of this great Nation.

Thank you for listening, I will be pleased to answer any questions you may have.

[9] http://www.nsf.gov/mps/ast/aaac/reports/annual/AAAC_2015-16_Report.pdf